FORMING PARTIAL-DEPTH FEATURES IN POLYMER FILM

RELATED APPLICATION

This application is related to application having Serial No. xxx/xxx,xxx entitled WAFER-LEVEL MOAT STRUCTURES, filed on even date with this application, assigned to the same assignee as the assignee of this application, which is hereby fully incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to imaging in a photo-imageable polymer film on a semiconductor wafer, and more particularly to forming a structural feature, for example, a via, partially through a thickness of the polymer film.

2. Description of the Related Art

A wafer-level chip scale package (CSP) is a package for an integrated circuit that is substantially the size of the integrated circuit or of a flip chip, which uses a wafer-level processing technique. Unlike a flip chip, the wafer-level CSP has one or more passivation layers on the active side of the die. Each passivation layer typically comprises a layer of photo-imageable polymer film. The wafer-level CSP is smaller than a standard ball grid array (BGA), typically uses metal traces of a re-distribution layer (RDL) to route solder ball pads to standard pitches, and uses CSP-size solder balls on the re-routed pads. A wafer-level CSP uses a standard surface mount technology assembly process that is also used for BGAs, and does not require underfill.

When a polymer film is imaged, it is generally desired that a structural feature, such as a via or a hole, is achieved through the entire film thickness, or layer. All photo-imageable polymer film systems and processes, have some minimum size, or critical dimension, for example, ten (10) microns, that is resolvable to open the structural feature, or feature, completely through the layer. Assuming that the layer is in an x-y plane of an x-y-z coordinate system, a depth of the feature is in the z direction. A structural feature that penetrates completely through the layer of polymer film is a full-depth feature. To make a full-depth feature, the smaller of the dimensions of the

feature in the x-y plane, must be larger than the critical dimension. A feature in which the smaller of the dimensions of the feature in the x-y plane is smaller than the critical dimension, is a partial-depth feature and does not penetrate completely through the layer.

The critical dimension is determined by many factors including the type of material comprising the layer, the thickness of the layer, the exposure tool used, several exposure process parameters such as exposure energy, exposure time and depth of focus, and several developing process parameters such as the developing solution, temperature and time.

A photomask, which comprises a UV light-blocking material, such as chrome, disposed on a transparent glass or quartz plate, is used to expose a polymer film. A prior art photomask has chrome disposed in patterns that have a shape and size of the features that are desired to be produced in the polymer film. In the case of a negative acting polymer film, polymer film exposed to light becomes cross-linked and cannot be developed, i.e., removed, from the exposed area. In the case of a positive acting film, the polymer film exposed to light is removed during development.

Using prior art methods, a partial-depth feature in which its smaller dimension is greater than the critical dimension cannot be formed in a polymer film at the same time, i.e., during a single series of photo-imaging steps using one photomask, as a full-depth feature is formed.

OBJECTS OF THE INVENTION

It is therefore an object of the present invention to overcome the disadvantages of the prior art. In particular, it is an object of the present invention to provide a photomask with which a full-depth feature and a partial-depth feature can substantially simultaneously be produced in a polymer film.

It is another object of the present invention to provide a method of forming a full-depth feature and a partial-depth feature substantially simultaneously in a polymer film.

It is still another object of the present invention to provide a method of reducing the reflectivity of a surface of the polymer layer.

It is yet another object of the present invention to provide a method of marking information on the surface of the polymer layer.

It is a further object of the present invention to provide a method to thin a polymer layer.

These and other objects of the present invention will become apparent to those skilled in the art as the description thereof proceeds.

SUMMARY OF THE INVENTION

Briefly described, and in accordance with a preferred embodiment thereof, the present invention relates to a photomask used to form a partial-depth feature in a polymer film on a semiconductor wafer, and, substantially simultaneously, used to form a full-depth feature in the polymer film on the semiconductor wafer during one series of photo-imaging steps using exposure tools that are capable of resolving a minimum resolvable size to form a feature completely through the polymer film. The polymer film has a film thickness, and the partial-depth feature has a depth substantially less than the film thickness. The full-depth feature has a depth approximately equal to the film thickness. The photomask includes a transparent plate and at least one full-depth producing pattern. Each full-depth producing pattern includes an area of UV light-blocking material disposed on the transparent plate. The area has a larger dimension and a smaller dimension, and the smaller dimension is equal to or greater than minimum resolvable size. The photomask also includes a partial-depth producing pattern that includes a plurality of areas of UV light-blocking material disposed on the transparent plate. Each area of the plurality of areas has a larger dimension and a smaller dimension, and the smaller dimension is less than the minimum resolvable size, and each area is spaced from another area by a distance less than the minimum resolvable size.

Preferably, the partial-depth producing pattern produces only one partial-depth feature in the polymer film.

Another aspect of the present invention relates to a method of forming a partial-depth feature in a polymer film on a semiconductor wafer using exposure tools that have a critical dimension, which includes the steps of: (a) disposing on a photomask a partial-depth producing pattern that includes a plurality of areas of UV light-blocking material, in which each area has a smaller dimension less than the critical dimension and is spaced apart a distance less than the critical dimension; and (b) exposing the polymer film to the partial-depth producing pattern on the photomask in a manner substantially the same as when exposing the polymer film to full-depth producing images on the photomask; and (c) developing the polymer film exposed to the partial-depth producing pattern on the photomask in a manner substantially the same as when developing the polymer film exposed to a full-depth producing pattern on the photomask.

A further aspect of the invention relates to a method of altering an optical property of a surface of a polymer film, which includes the steps of: (a) disposing a layer of polymer film on a semiconductor wafer, in which the layer has a surface with a first optical property; (b) exposing the polymer film to a partial-depth producing pattern on a photomask; and (b) developing the exposed polymer film such that the surface of the polymer film has a second optical property.

Yet another aspect of the invention relates to a method to inscribe markings on a surface of a polymer film, which includes the steps of: (a) disposing a layer of polymer film on a semiconductor wafer, in which the layer has a surface with no discernable markings; (b) exposing the polymer film to a partial-depth producing pattern on a photomask, in which the partial-depth producing pattern has one or more preselected shapes; and (b) developing the exposed polymer film such that the one or more preselected shapes are discernable on the surface of the polymer film.

Still another aspect of the invention relates to a method of making thinner a layer of a polymer film disposed on a semiconductor wafer, which includes the steps of: (a) providing a layer of polymer film on the semiconductor wafer, in which the layer has a first thickness; (b) exposing at least a portion of the polymer film to a partial-depth producing pattern on at least a portion of a photomask; and (b) developing the polymer film such that the at least a portion of the polymer film exposed to the partial-depth producing pattern has a second thickness, and in which the second thickness is smaller than the first thickness.

Yet a further aspect of the invention relates to a method of using a photomask to form a feature in a layer of a negative-acting photo-imageable polymer film, in which the feature has a smaller dimension greater than a critical dimension of photolithography tools used, and in which the feature penetrates only partially through the layer. The polymer film has a minimum structurally sound material width. The method includes the steps of: (a) disposing on the photomask a plurality of areas of chrome, each area has a smaller dimension smaller than the critical dimension and spaced is apart a distance smaller than the critical dimension; (b) exposing the polymer film to UV light shining through the photomask such that the UV light is blocked by the areas of chrome; and (c) developing the polymer film such that portions of the polymer film not exposed to the UV light and portions of the polymer film exposed to the UV light that have a

width narrower than the minimum structurally sound material width, are removed.

Other aspects, features and advantages of the present invention will become apparent to those skilled in the art from the following detailed description and the accompanying drawings. It should be understood however that the detailed description and specific examples, while indicating preferred embodiments of the present invention, are given by way of illustration only and various modifications may naturally be performed without deviating from the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described with greater specificity and clarity with reference to the following drawings, in which:

FIG. 1 is a top view of a simplified prior art wafer-level CSP;

FIG. 2 is a top view of a simplified wafer-level CSP constructed in accordance with the preferred embodiments of the invention, showing a moat around each solder ball pad;

FIG. 3 is an enlarged simplified top view of area A of a wafer used to form the wafer-level CSP shown in FIG. 2, showing a solder ball with a polymer collar, surrounded by a full-depth moat, prior to heating of the wafer;

FIG. 4 is a cross-sectional view of FIG. 3 through cut-line 4-4;

FIG. 5 is an enlarged simplified top view of area A of the wafer used to form the wafer-level CSP shown in FIG. 2, showing the solder ball with the polymer collar, surrounded by the full-depth moat, subsequent to heating of the wafer;

FIG. 6 is a cross-sectional view of FIG. 5 through cut-line 6-6;

FIG. 7 is a simplified top view of area B of the wafer used to form the wafer-level CSP shown in FIG. 2, showing a first embodiment of a partial-depth moat, formed by a plurality of lines;

FIG. 8 is a cross-sectional view of FIG. 7 through cut-line 8-8;

FIG. 9 is a simplified top view of area C of the wafer used to form the wafer-level CSP shown in FIG. 2, showing a second embodiment of the partial-depth moat, formed by a multiplicity of circles;

FIG. 10 is a cross-sectional view of FIG. 9 through cut-line 10-10;

FIG. 11 is a photomicrograph of a portion of a prior art wafer showing the solder ball and the polymer collar following heating of the wafer;

FIG. 12 is a photomicrograph of a portion of a wafer in accordance with the invention showing the solder ball and the polymer collar following heating of the wafer;

FIG. 13 is a photomicrograph of a portion of a wafer in accordance with the invention, showing the partial-depth moat formed by a plurality of lines around each solder ball pad;

FIG. 14 is a photomicrograph of a portion of a wafer in accordance with the invention,

showing the partial-depth moat formed by a multiplicity of circles around each solder ball pad;

FIG. 15 is a photomicrograph of a portion of a wafer in accordance with the invention, with the partial-depth moat formed by a plurality of lines around each solder ball pad, showing the solder ball and the polymer support collar following heating of the wafer;

FIG. 16 is a photomicrograph of a cross-section of the partial-depth moat shown in FIG. 17;

FIG. 17 is a photomicrograph of a cross-section of a wafer in accordance with the invention, with the partial-depth moat formed by a multiplicity of circles;

FIG. 18 is a photomicrograph of a portion of a wafer in accordance with the invention, showing the full-depth moat around the solder ball pad, and in which the full-depth moat is interrupted by a metal trace;

FIG. 19 is a simplified plan view of a portion of a photomask in accordance with the invention;

FIG. 20 is a plan view enlargement of area A of the photomask of FIG. 19 showing a full-depth producing chrome pattern;

FIG. 21 is a plan view enlargement of area B of the photomask of FIG. 19 showing a partial-depth producing chrome pattern, in the form of three concentric lines of chrome;

FIG. 22 is a plan view enlargement of area C of the photomask of FIG. 19 showing a partial-depth producing chrome pattern, in the form of four concentric rings of circles of chrome;

FIG. 23 is a simplified cross-sectional view of a small portion of the photomask with a partial-depth producing chrome pattern, and a cross-sectional view of a small portion of the wafer after exposure; and

FIG. 24 is the portion of the wafer of FIG. 23 after developing.

For simplicity and clarity of illustration, the drawing figures illustrate the general manner of construction, and descriptions and details of well-known features and techniques are omitted to avoid unnecessarily obscuring the invention. Additionally, elements in the drawing figures are not necessarily drawn to scale.

DESCRIPTION OF THE PREFERRED EMBODIMENT

It should be understood that the embodiments discussed below are only examples of the many advantageous uses of the innovative teachings herein. In general, statements made in the specification of the present application do not necessarily limit any of the various claimed inventions. Some statements may apply to some inventive features but not to others. In general, unless otherwise indicated, singular elements may be in the plural and vice versa with no loss of generality, for example, “one die”, "two die". The terms first, second, third, and the like, in the description and in the claims, if any, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order. The terms top, front, side, and the like, in the description and in the claims, if any, are used for descriptive purposes and not necessarily for describing relative positions. All measurements are approximate, for example, "30 microns" means "30 microns, more or less".

FIG. 1 is a top view of a simplified prior art wafer-level CSP **100** comprising a prior art integrated circuit, or die, **102** and a plurality of solder ball pads **106**.

FIG. 2 is a top view of a simplified wafer-level CSP **200** constructed in accordance with the preferred embodiments of the invention, comprising a single integrated circuit, or die, **202** with a moat **204** around each solder ball pad **206**. The die **202** is one of a plurality of die from a larger semiconductor wafer or "wafer" (not shown). Typically, there are 200-700 die per wafer. A wafer-level CSP design is described in U.S. Patent No. 6,287,893 entitled METHOD FOR FORMING CHIP SCALE PACKAGE, issued September 11, 2001, to Elenius et al., assigned to the assignee of the present invention, which is hereby fully incorporated herein by reference. The moat **204** is a ring-shaped (when seen in a top view) via formed in the surface of a passivation layer disposed on the wafer during a wafer-level processing step. By "wafer-level processing" it is meant, for example, that the moats **204** are formed in each die **202** prior to the die being cut from the wafer. Preferably, the passivation layer is a photo-imageable polymer film. The photo-imageable polymer film is typically benzocyclobutene (BCB), although the invention is useful with photo-imageable films of other materials. The moat **204** is used to confine and contain some material of the polymer collar that temporarily becomes much less viscous, or "liquefies", when the wafer is heated to the reflow temperature of solder ball metal during a

subsequent wafer-level CSP **200** processing step.

FIG. 3 is an enlarged simplified top view of portion **300**, indicated by area A of FIG. 2, of a wafer used to form the wafer-level CSP **200**, showing a solder ball **308** with a polymer collar **310** at a central feature **414** (see FIG. 4), surrounded by a full-depth moat **312**, prior to heating of the wafer. Preferably, the polymer collar material is XNF-1502 manufactured by Ablestik Laboratories, of Rancho Dominguez, CA. Alternatively, another material is used for the polymer collar **310**. The use of a polymer collar around a solder ball is described in U.S. Patent No. 6,578,755 entitled POLYMER COLLAR FOR SOLDER BUMPS, issued June 17, 2003, to Elenius et al., assigned to the assignee of the present invention, which is hereby fully incorporated herein by reference. The central feature **414** has a diameter **313** of two hundred eighty (280) microns. The full-depth moat **312** defines a region **314** within the moat, and a region **316** without, or outside of, the moat. The full-depth moat **312** has a width **315** of thirty (30) microns. A distance **317** between the inside edge of full-depth moat **312** and the outside edge of the central feature **414** is seventy-five (75) microns. The solder ball **308** has a diameter **416** (see FIG. 4) of 300-350 microns.

FIG. 4 is a cross-sectional view of FIG. 3 through cut-line 4-4. The wafer typically comprises at least one layer of silicon, although the invention is also useful with wafers comprising other semiconductor materials. The one silicon layer **402** represents the wafer semiconductor substrate and all its layers, ready for CSP manufacturing. For simplification, the details of the wafer are not shown. The silicon layer **402** typically is coated with silicon nitride or silicon dioxide, dielectrics that generally do not conduct electricity, as a thin passivation layer (not shown), with openings over selected aluminum bond pads (not shown) of the integrated circuits of the wafer. The silicon nitride or silicon dioxide thin passivation layer is typically not placed on the wafer during CSP manufacturing, but is part of the wafer as it exists prior to CSP manufacturing. All other layers illustrated in FIG. 4 are typically placed on the wafer in the course of manufacturing the wafer-level CSP from the wafer.

A first polymer layer **404** of photo-imageable polymer film is disposed over the thin passivation layer. The first polymer layer **404** is typically 4-5 microns thick. A metalization layer is disposed on the first polymer layer **404**, and over any exposed aluminum bond pads. The

metalization layer includes an under bump metalization (UBM) area, or solder ball pad, **206** and a re-distribution layer (RDL) **406**. The RDL comprises metal traces that form a conductive path between each solder ball pad **206** and any associated aluminum bond pad not positioned at the same x-y coordinates as the solder ball pad. A second polymer layer **412** of photo-imageable polymer film is disposed on the first polymer layer **404** and the metalization layer. The second polymer layer **412** is typically 4-5 microns thick. The first polymer layer **404** and the second polymer layer **412** are typically of the same material, preferably a CYCLOTENE™ 4022-35 BCB passivation polymer, manufactured by Dow Chemical Company of Midland, MI, as in a standard, two-layer ULTRA CSP® package. Alternatively, another one material is used for both photo-imageable polymer layers. As a further alternative, different materials are used for each photo-imageable polymer layer. The full-depth moat **312** is also used on wafer-level CSPs **200** with a single polymer layer of 4-5 microns in thickness. Typically, when a single polymer layer is used, no RDL is necessary.

The central feature **414** is a via that penetrates completely through both the first polymer layer **404** and the second polymer layer **412** of a finished wafer-level CSP. Using photo-imaging means well known to those skilled in the art, the central feature **414** is formed (i.e., opened) in the first polymer layer **404** prior to deposition of the second polymer layer **412**, thereby exposing any associated aluminum bond pad positioned at the same x-y coordinates as the solder ball pad **206**. The silicon nitride or silicon dioxide thin passivation layer is exposed at the bottom of the central feature **414** in designs wherein the associated aluminum bond pad is not positioned at the same x-y coordinates as the solder ball pad **206**. The first polymer layer **404** is then cured by baking in an oven at a temperature and for a period required for the polymer to polymerize. The metalization layer, which typically comprises layers of aluminum, nickel vanadium and copper, is sputtered over selected portions of the first polymer layer **404**, over any exposed aluminum bond pads, and over the silicon nitride or silicon dioxide at the bottom of the central feature **414**. Next, the second polymer layer **412** is disposed on the first polymer layer **404** including on the portions of the first polymer layer having metalization. Using photo-imaging means well known to those skilled in the art, full-depth moat **312** is formed in the wafer completely through the second polymer layer **412**, and, at the same time, the central feature **414** is re-opened down to the

metalization layer, or solder ball pad **206**. The first polymer layer **404** is exposed at the bottom of full-depth moat **312**. The full-depth moat **312** does not overlie the RDL **406**, as shown in FIG. 4. Preferably, full-depth moat **312** is used in cases where the moat does not overlie the RDL **406**.

FIG. 5 is an enlarged simplified top view of the portion **300**, showing the solder ball **308** with the polymer collar **310**, surrounded by full-depth moat **312**, subsequent to heating of the wafer. As the solder ball **308** is reflowed, some liquefied material of the polymer collar **310** spreads out, but advantageously, only into region **314** within full-depth moat **312**. The full-depth moat **312** confines and contains the liquefied polymer collar material, and advantageously prevents it from spreading beyond the moat into region **316** outside the moat. During later stages of the reflow process, the liquefied polymer collar material that flowed into region **314** becomes much more viscous and hardens or "solidifies", and forms a residual **502**. FIG. 5 shows that most of the region **314** within full-depth moat **312** contains residual **502** of polymer collar material. The residual **502** is semi-transparent. The residual **502** does not necessarily completely fill the region **314** within full-depth moat **312** (though it may), nor does it necessarily spread out equally in all directions from the main portion of the polymer collar **310** (though it may). Therefore, there might be some random-looking appearance of the residual material as FIG. 5, however, the residual **502** is contained/controlled by full-depth moat **312** and the spread of the residual therefore is limited by the moat. In some instances the residual **502** may completely cover the bottom surface of full-depth moat **312**.

FIG. 6 is a cross-sectional view of FIG. 5 through cut-line 6-6. The full-depth moat **312** retains residual **502** of polymer collar material that spreads out along the surface of the second polymer layer **412** away from the polymer collar **310**. The flow of the residual **502** occurs prior to, and during solder reflow. Without the presence of full-depth moat **312**, the residual **502** flows out in a random pattern and for a greater distance, and, as a result, is cosmetically unacceptable. The purpose of full-depth moat **312** is to contain the flow of the residual and prevent/minimize its flow beyond the moat, thereby enhancing the cosmetic appearance of the wafer-level CSP. As a result of the presence of full-depth moat **312**, residual **502** flows a shorter distance from the polymer collar, the extent of residual flow is more nearly uniform in all directions, and the outer edge of the flow is thereby more nearly circular. The full-depth moat **312** surrounds the central

feature **414**; alternatively, the full-depth moat is a stand-alone feature.

FIG. 7 is a simplified top view of the portion **300**, indicated by area B of FIG. 2, of the wafer used to form the wafer-level CSP **200**, showing a first embodiment of a partial-depth moat **712** formed by a plurality of lines **701**, **702** and **703** around the central feature **414**, preferably using the photo-imaging means in accordance with the invention. The partial-depth moat **712** has a width **715** of twenty-three (23) microns. A distance **717** between the inside edge of partial-depth moat **712** and the outside edge of the central feature **414** is seventy-five (75) microns. It should be noted that the invention is not limited to using three (3) lines. Any number of lines greater than one (1) can be used.

FIG. 8 is a cross-sectional view of FIG. 7 through cut-line 8-8. Using means well known to those skilled in the art, the central feature **414** is formed completely through both the second polymer layer **412** and the first polymer layer **404**. The solder ball pad **206** is exposed at the bottom of the central feature **414**. The partial-depth moat **712** is formed in the wafer partially through the second polymer layer **412**. The second polymer layer **412** is exposed at the bottom of partial-depth moat **712**. The partial-depth moat **712** does not penetrate to the first polymer layer **404**. The partial-depth moat **712** has a moat depth **801** of 1-99% of the thickness of the second polymer layer **412**. Alternatively, the partial-depth moat **712** is used on wafer-level CSPs **200** having a single polymer layer of 4-5 microns in thickness. In such case, partial-depth moat **712** has a moat depth **801** of 1-99% of the thickness of the single polymer layer. In FIG. 8, the partial-depth moat **712** overlies the RDL **406**. The RDL **406** is not exposed through partial-depth moat **712**. Advantageously, the partial-depth moat **712** may cross underlying metal traces without exposing the RDL **406**.

FIG. 9 is a simplified top view of the portion **300**, indicated by area C of FIG. 2, of the wafer used to form the wafer-level CSP **200**, showing a second embodiment of the partial-depth moat. Partial-depth moat **912** is formed by a multiplicity of circles **913** around the central feature **414**, preferably using photo-imaging means in accordance with the invention. The multiplicity of circles **913** are in the form of four (4) concentric rows **901-904** of closely-packed circles. The partial-depth moat **912** has a width **915** of twenty-eight (28) microns. A distance **917** between the inside edge of partial-depth moat **912** and the outside edge of the central feature **414** is

seventy-five (75) microns. It should be noted that the invention is not limited to using four (4) concentric rows of circles. Any number of rows can be used, provided that a plurality of circles is used. Partial-depth moats **712** and **912** surround the central feature **414**; alternatively, the partial-depth moats are stand-alone features.

FIG. 10 is a cross-sectional view of FIG. 9 through cut-line 10-10. Using means well known to those skilled in the art, the central feature **414** is formed in the wafer completely through both the second polymer layer **412** and the first polymer layer **404**. The solder ball pad **206** is exposed at the bottom of the central feature **414**. The partial-depth moat **912** is formed in the wafer partially through the second polymer layer **412**. The partial-depth moat **912** does not penetrate to the first polymer layer **404**, therefore, the second polymer layer **412** is exposed at the bottom of partial-depth moat **912**. The moat depth **801** of partial-depth moat **912** is 1-99% of the thickness of the second polymer layer **412**. Alternatively, the partial-depth moat **912** is used on wafer-level CSPs **200** having a single polymer layer of 4-5 microns in thickness. In such case, partial-depth moat **912** has a moat depth **801** of 1-99% of the thickness of the single polymer layer. The partial-depth moat **912** overlies the RDL **406**. As shown in FIG. 10, the RDL **406** is not exposed through partial-depth moat **912**. Advantageously, partial-depth moat **912** may cross underlying metal traces without exposing the RDL **406**.

FIG. 11 is a photomicrograph of a portion of a prior art wafer showing the solder ball **308** and the polymer collar **310** following heating of the wafer. The residue **502** of polymer collar material extends an irregular distance from the solder ball **308**. After the central features **414** are formed in the wafer, a polymer collar **310**, which is a fluxing polymer material, is applied to the central feature **414**, and then solder balls **308** are placed onto the fluxing polymer spots. The wafer is subsequently processed through reflow and cure processes where the polymer collar **310** softens and has a tendency to flow, and then cure. As can be seen in FIG. 11, without the moats **204**, the final appearance of the residual **502** is random and uncontrolled.

FIG. 12 is a photomicrograph of a portion of a wafer in accordance with the invention, showing the solder ball **308** and the polymer collar **310** following heating of the wafer. FIG. 12 illustrates the results of the same processing steps and materials used on the prior art wafer in FIG. 11, but with moats **204**. FIG. 12 shows that the moat **204** confines and contains the residual

502 within the moat confines. The moat **204** assists in creating a concentric/uniformly shaped, cured fluxing polymer, and the moat inhibits random flow of the residual **502** from the polymer collar **310**.

FIG. 13 is a photomicrograph of a portion of a wafer in accordance with the invention, showing partial-depth moat **712** formed by the plurality of lines **701**, **702** and **703** around each solder ball pad **206**. There is no solder ball or polymer collar on the wafer shown in FIG. 13.

FIG. 14 is a photomicrograph of a portion of a wafer in accordance with the invention, showing partial-depth moat **912** formed by a multiplicity of circles **913** around each solder ball pad **206**. There is no solder ball or polymer collar on the wafer shown in FIG. 14.

FIGS. 15-17 are photographs made with a scanning electron microscope. FIG. 15 is a photomicrograph of a portion of a wafer in accordance with the invention, with partial-depth moat **712** formed by the plurality of lines **701**, **702** and **703** around the central feature **414**, showing the solder ball **308** and the polymer collar **310** following heating of the wafer.

FIG. 16 is a photomicrograph of an enlarged cross-section of partial-depth moat **712** shown in FIG. 15. The partial-depth moat **712** shown in FIGS. 15 and 16 is produced by a photomask having three (3) concentric seven (7) micron wide chrome lines **701**, **702** and **703** separated by one (1) micron wide spaces, using the method in accordance with the invention. Although produced by three lines, a single, partial-depth moat is formed, as shown in FIGS. 15 and 16. The partial-depth moat **712** of FIGS. 15 and 16 is twenty-three (23) microns wide and has a moat depth of 2.1 microns, which is about 60% through the second polymer layer **412**.

FIG. 17 is a photomicrograph of a cross-section of a wafer in accordance with the invention, showing partial-depth moat **912** formed by a multiplicity of circles **913**. The partial-depth moat **912** shown in FIG. 17 is produced by a photomask having four (4) rows of closely-packed seven (7) micron diameter chrome circles, using the method in accordance with the invention. Although produced by a multiplicity of circles, a single, partial-depth moat is formed, as shown in FIG. 17. The partial-depth moat **912** shown in FIG. 17 is twenty-eight (28) microns wide and has a moat depth of 2.2 microns, which is about 64% through the second polymer layer **412**.

FIG. 18 is a photomicrograph of a portion of a wafer in accordance with the invention,

showing full-depth moat **312** around the solder ball pad **206**, and in which the full-depth moat is interrupted by a metal trace. One of the partial-depth moats **712** and **912** is preferably used where a moat overlies a metal trace. Alternatively, the full-depth moat **312** is used, and the full-depth moat is preferably interrupted at the metal trace, as shown in FIG. 18, so as not to expose the metal trace. As a further alternative (not shown), when exposing a particular metal trace is not deleterious, full-depth moat **312** crosses a metal trace, thereby exposing the RDL **406**.

The invention advantageously keeps the applied material in a concentric shape/volume for either structural and/or cosmetic purposes. The ability of the moat **204**, **312**, **712** and **912** to confine the residual **502** depends upon the volume of the moat, the depth of the moat, and the distance **317**, **717** and **917** from central feature **414**. Advantageously, it is easier to perform automatic optical inspection of bumped wafers when the spread of the residual **502** is controlled by a moat.

FIG. 19 is a plan view of a portion of a photomask **1900**, corresponding to one die **202**, used to make features in a layer of negative-acting polymer film. On the full photomask (not shown), there is a plurality of such portions that mimic the die layout of the entire wafer. For conciseness, the portion of the photomask **1900** is also referred to as the photomask **1900**. The photomask **1900** comprises a transparent plate, preferably glass or quartz **1903**, on which an ultraviolet (UV) light-blocking material, preferably chrome **1905**, is disposed in preselected patterns. The photomask **1900** is used to expose, or cause a chemical change in, preselected portions of the polymer film, thereby rendering the polymer film photo-definable after developing. A prior art photomask has chrome disposed in patterns that have a substantially same shape and size of the features that are desired to be produced in the polymer film. In the case of a negative acting polymer film, the polymer film exposed to light becomes cross-linked and cannot be developed, i.e., removed, from the exposed area. In the case of a positive acting polymer film, the polymer film exposed to light is removed during developing.

The photomask **1900** is used to form features in a layer of negative-acting polymer film, such as the second polymer layer **412**. In FIG. 19, dark areas are chrome **1903** and the light area is quartz **1905**. The portion of the photomask **1900** is used to form forty-nine (49) central features **414** and a moat **204** around each central feature of one die **202**. When the polymer film

is imaged, it is generally desired that features, such as central feature **414** and full-depth moat **312**, are achieved through the entire film thickness, or layer. The photomask **1900** in accordance with the invention is used to make full-depth features; however, the photomask also advantageously makes partial-depth features during a same series of photo-imaging steps.

All photo-imageable polymer film systems and processes, have some minimum size, or critical dimension, that is resolvable to open the structural feature, or feature, completely through the polymer layer. In the examples described in the preferred embodiment, the critical dimension for a linear structural feature, including a curved linear structural feature, is ten (10) microns and for a circular structural feature is thirty (30) microns. Assuming that the polymer layer is in an x-y plane of an x-y-z coordinate system, a depth of the feature is in the z direction. When it is desired that the feature penetrate completely through the polymer layer, the feature size, i.e., the smaller of the dimensions in the x-y plane, of the feature must be larger than the critical dimension. A feature having the feature size smaller than the critical dimension does not penetrate completely through the polymer layer.

The critical dimension is determined by many factors including the type of material comprising the polymer layer, the thickness of the polymer layer, the exposure tool used, several exposure process parameters such as exposure energy, exposure time and depth of focus, and several developing process parameters such as the developing solution, temperature and time. The method in accordance with the invention utilizes conventional expose/develop technology to create structured features in polymer films. The method in accordance with the invention takes advantage of the limitations of conventional exposure/developing tools, which cannot make full-depth features in polymer films smaller than the critical dimension.

Preferably, the structured feature is in the shape of a moat **204**, a full-depth moat **312** that penetrates fully through the polymer film of the second polymer layer **412**, or a partial-depth moat **712** and **912** that penetrates to a partial-depth into the polymer film of the second polymer layer. The method in accordance with the invention advantageously allows for the creation of a partial-depth feature utilizing the same process/steps/sequences performed at the same time that a full-depth feature is formed through the entire film thickness.

The chrome pattern on the photomask **1900** comprises more than one chrome area, each

area having two dimensions in the x-y plane of the photomask. The lesser of the two dimensions is the smaller dimension. When it is desired that the feature penetrates only partially through the polymer layer, the photomask in accordance with the invention utilizes a plurality of chrome areas, each chrome area having a smaller dimension less than the critical dimension, and conventional exposure/developing tools and methods are used in a same manner as if a full-depth feature were to be formed. When it is desired that the feature penetrates completely through the polymer layer, the smaller dimension of the chrome area must be larger than the critical dimension.

Preferably, the photomask **1900** has a plurality of chrome patterns, each pattern having a different smaller dimension, on a single photomask. This allows for the creation of a developed polymer film not only with multiple types of partial-depth features but also with full-depth features, such as through vias. Advantageously, all the features are created in one series of photo-imaging steps. For example, photomask **1900** shows three (3) areas, indicated by area A, area B and area C, within a region of the photomask corresponding to a single die **202**. Area A forms a full-depth feature, while area B and area C each form a partial-depth feature in a different way. For simplicity of illustration, area A, area B and area C are shown being within the region of the photomask corresponding to the single die **202**; however, in general, they are on the photomask at locations corresponding to more than one die of the wafer.

FIG. 20 is an enlarged portion **2000** of the photomask **1900**, indicated by area A of FIG. 19, showing a full-depth producing pattern of chrome. The dark areas are chrome and the light area is clear quartz. The full-depth producing pattern of chrome comprises a central chrome circle **2002** and a chrome ring **2004** around the central chrome circle, disposed on the photomask **1900**. The central chrome circle **2002** has a diameter **2006** of two hundred eighty (280) microns, which is also the smaller dimension of the central chrome circle. The central chrome circle **2002** on the photomask **1900** produces the central feature **414** in the second polymer layer **412**. The chrome ring **2006** has a width **2008** of thirty (30) microns and a diameter **2010** of three hundred seventy-five (375) microns. The smaller dimension of the chrome ring **2004** is thirty (30) microns. The chrome ring **2004** produces the full-depth moat **312** in the second polymer layer **412**. The width **2008** of the chrome ring **2004** is greater than the minimum width-opening

capability of the process, or critical dimension, therefore, the thirty (30) micron wide chrome ring forms a full-depth moat **312**, having a width **315** of thirty (30) microns, in the second polymer layer **412**. Therefore, area A of the photomask **1900** in accordance with the invention is used to form full-depth features.

FIG. 21 is an enlarged portion **2100** of the photomask **1900**, indicated by area B of FIG. 19, showing the central chrome circle **2002**, surrounded by a partial-depth producing chrome pattern **2104**, disposed on the quartz of the photomask. The partial-depth producing chrome pattern **2104** comprises three concentric chrome lines **2101-2103**, each chrome line having a width **2105** of seven (7) microns. The three concentric chrome lines **2101-2103** are one (1) micron apart. For clarity of illustration, the space between the three concentric chrome lines **2101-2103** is exaggerated. Therefore, the partial-depth producing chrome pattern **2104** on the photo mask has a width **2106** of twenty-three (23) microns. The diameter **2107** of the partial-depth producing chrome pattern **2104** is three hundred seventy-five (375) microns, which varies depending on the diameter of the solder ball **308** and the solder ball pitch. The smaller dimension (the width **2105**) of the three concentric chrome lines **2101-2103** is seven (7) microns. The smaller dimension of each of the three concentric chrome lines **2101-2103** is less than the critical dimension. The three concentric chrome lines **2101-2103** on the photomask **1900** act together to form a single partial-depth moat **712**, having a width **715** of twenty-three (23) microns, in the second polymer layer **412**. Area B of the photomask **1900** is used to form one or more partial-depth features in accordance with the invention while also being used to form one or more full-depth features, at the same time.

FIG. 22 is an enlarged portion **2200** of the photomask **1900**, indicated by area C of FIG. 19, showing the central chrome circle **2002** and a partial-depth producing chrome pattern **2205** disposed on the quartz of the photomask. The central chrome circle **2002** on the photomask **1900** is surrounded by a plurality of the small chrome circles **2206** forming four (4) concentric rings **2201-2204** of the small chrome circles. The partial-depth producing chrome pattern **2205** comprises the four concentric rings **2201-2204** of the small chrome circles **2206**. Each small chrome circle **2206** has a diameter of seven (7) microns. The partial-depth producing chrome pattern **2205** on the photomask **1900** has a width **2207** of twenty-eight (28) microns. The

diameter of each of the small chrome circles **2206** on the photomask **1900** is less than the critical dimension. The plurality of small chrome circles **2206** on the photomask **1900** act together to form the single partial-depth moat **912** having a width **915** in the second polymer layer **412**. Area C of the photomask **1900** is used to form one of more partial-depth features in accordance with the invention while also being used to form one or more full-depth features, at the same time.

FIG. 23 is a simplified cross-sectional view of a small portion of the photomask **1900** with the partial-depth producing chrome pattern **2104**, and of a simplified cross-sectional view of a small portion of the wafer. The small portion of the wafer comprises only a small portion of the second polymer layer **412**, which is preferably composed of photo-imageable polymer film **2301**. The photo-imageable polymer film **2301** is shown after exposure to UV light, but prior to developing. A typical distance **2302** between the photomask **1900** and the polymer film **2301** is thirty-five (35) microns. The first polymer layer **404** (not shown in FIG. 23) is cured and is, therefore, not alterable by exposure to UV light. The second polymer layer **412**, on the other hand, has not yet been cured and is alterable with UV light. A source (not shown) of UV light is reflected off a mirror **2303**. For a particular aligner tool used, the mirror **2303** is a distance of three to five feet from the photomask. UV light directed from the mirror **2303** toward the photomask **1900**, as indicated by arrows **2311-2319**. The smaller dimension of the individual chrome lines **2101-2103** of the partial-depth producing chrome pattern **2104** shown in FIG. 23 is less than the critical dimension, i.e., the minimum dimension that the expose process is capable of resolving.

Where there is no chrome on the photomask **1900**, the UV light passes through the photomask, as indicated by arrows **2311**, **2313**, **2314**, **2316**, **2317** and **2319**, exposing portions of the second polymer layer **412**. The polymer film is a negative-acting polymer film, and portions of the second polymer layer **412** that were exposed to UV light, which are indicated on FIG. 23 by solid-line hatch marks, become cross-linked. The exact area of the surface **2320** of the polymer layer **412** that is protected by a UV light shadow created by the chrome is less than the area of the chrome because some of the UV light undercuts, or passes under the edge of, the chrome **2101-2103**. Some amount of UV light passes adjacent to the edges of the chrome **2101-2103** and is dispersed in various directions, including under the chrome, due to reflections within

the second polymer layer **412**. A small amount of UV light, as indicated, for example, by arrows **2313** and **2317**, passes through the second polymer layer **412** and reflects off the first polymer layer **404** and back up at some angle, as shown in FIG. 23. Although not shown in FIG. 23, most of the reflected UV light passes through both the first and the second polymer layers and reflects off the silicon layer **402** and the RDL **406** in a manner analogous to arrows **2313** and **2317**. Where there is chrome on the photomask **1900**, the UV light is blocked, as indicated by arrows **2312**, **2315** and **2318**. The reflected UV light exposes areas in the second polymer layer **412** that are under the chrome **2101-2103**, but close to the edge of the chrome. The portions **2321-2323** of the second polymer layer **412** that are not exposed, and, therefore, are not cross-linked are indicated by dashed-line hatch marks. The reflected UV light also exposes portions **2331-2333** in the second polymer layer **412** that are completely under the portions **2321-2323** that are not exposed.

FIG. 24 shows the small portion of the wafer of FIG. 23 after the wafer is processed with a developing chemical that removes all portions of the second polymer layer **412** not exposed by UV light passing through the one (1) micron spaces between the seven (7) micron chrome patterns on the photomask **1900**. The portions **2321-2323** of the second polymer layer **412** that are shown with dashed-line hash marks in FIG. 23 are removed in FIG. 24.

In FIG. 24, the portions **2321-2323** of the second polymer layer **412** that are under the chrome **2101-2103** on the photomask **1900** are removed during developing. The photo-imageable polymer film does not cross-link in the portions **2321-2323** of the polymer film layer, i.e., in the polymer material that is near a surface **2320** closest to the photomask **1900**, and, as a result, the portions are removed during developing. The amount of film thickness in the portions **2321-2323** that is not cross-linked during the exposure process is a function of the (a) the critical dimension used for the feature, (b) the exposure energy, (c) the depth of focus of the exposure tool, (d) the type of polymer exposed, and (e) the exposure tool used.

The developing process also plays a role in the amount of film thickness that is removed. The developing process is controlled by the (a) the developing solution used, (b) the temperature of the develop process, and (c) the amount of overdevelop that is done. The developing process also removes some thin, upper portions **2410** and **2411** of the second polymer layer **412** near the

surface **2320**, which were exposed by UV light. Although the portions **2410** and **2411** of the second polymer layer **412** had been exposed by UV light, have become cross-linked, and, as a result, are not greatly affected by the develop chemical, the resulting elevated material that would be expected to remain is well below the minimum, structurally sound, material width for the second polymer layer. It has been determined that the minimum, structurally sound, material width **2413** is somewhat controllable, and is between 1-6 microns. During the developing process, the thin, upper portions **2410** and **2411** of the second polymer layer **412** are removed, and only the thicker, lower portions **2420-2421** remain, which had been under the one (1) micron spaces between the chrome **2101-2104** of the photomask **1900**.

Because the dimensions of the chrome patterns are preselected so that they are less than the minimum dimension that the expose process is capable of resolving, and because the spaces between the chrome are designed so that they are narrower than the minimum structurally sound line width for the second polymer layer **412**, the expose/develop processes results in a partial-depth feature **2401** with some depth variation in the second polymer layer **412**. The depth varies from a lesser depth **2415** to a greater depth **2416**. The width **2417** of the partial-depth feature **2401** is approximately the cumulative widths of all the chrome **2101-2103** and spaces between the chrome, combined. Because of the type of exposure tool used, the thickness of the second polymer layer **412**, the second polymer layer material type, and the expose/develop process parameters, the partial-depth feature **2401** has a smaller width **2418** at the bottom, which is farther from the photomask **1900**. The partial-depth feature **2401** has angled sidewalls **2419** and **2420**, and thus the width of the partial-depth feature decreases from top to bottom. The difference, or bias, is specific to the type of exposure tool used, the thickness of the second polymer layer **412**, the type of polymer material, and the expose/develop process parameters used. Using alternate photolithography tools, materials, thicknesses or other parameters changes the difference between the diameter **2417** and the smaller diameter **2418**.

FIGS. 7, 9 and 12-17 are examples of partial-depth moats created using closely spaced chrome patterns that individually are less than the critical dimension. The width of the partial-depth moats is greater than the critical dimension. Full-depth moats are created using a same photomask **1900** by preselecting a chrome segment having a smaller dimension that is larger

than the critical dimension.

It is also possible to use closely spaced segments of chrome other than lines and circles, which have smaller dimensions are less than the critical dimension, to create partial-depth features of various depths and widths in a polymer layer **404** and **412**. In such cases, the overall depth/width of the feature is a function of those items previously listed as relating to the expose/develop processes, as well as (a) the shape and size of the individual chrome segments, and (b) the spacing, or pitch, between the individual chrome segments. The individual closely spaced chrome segments have a cumulative effect during the exposure and developing processes resulting in a feature that is effectively one continuous structure whose width is an approximate sum of the widths of the individual chrome segments and the widths of the spaces therebetween used on the photomask **1900**. Using the method in accordance with the invention, it is possible to create a full-depth and a partial-depth moat of many widths, the width being limited only by the particular design, e.g., the pitch between solder ball pads, with which the moats are used. The chrome on a prior art photomask used to make a full-depth feature has a size and shape that is substantially the same as a size and shape of the full-depth feature. On the other hand, the chrome on the photomask **1900** used to make the partial-depth feature **712** and **912** in accordance with the invention has a size and shape that is different from the size and shape of the partial-depth feature because spaces between the chrome also contribute to the size and shape of the partial-depth feature.

The polymer film has features, created in accordance with the invention, that show very little or no evidence of the shape of the chrome pattern of the photomask **1900** used to create the feature; alternatively, the polymer film has features where the shape of the chrome pattern is easily seen. Instead of being in the shape of a moat, the partial-depth feature can be in the shape of discernible information, including visually readable information. For example, a die **202** is marked, or inscribed, with a lot number using partial-depth features by using a photomask **1900** having the chrome pattern in the shape of the lot number.

An optical property of the surface of the second polymer layer **412** is changeable using the method in accordance with the invention. In particular, the reflectivity of the surface of the second polymer layer **412** is reduced by forming a multiplicity of partial-depth features in the

polymer film, which is advantageous because reflections from the surface of a wafer-level CSP **200** could adversely affect robotic vision. It has been determined that forming a multiplicity of partial-depth features in the polymer film using a photomask **1900** with chrome lines having a width of 3-5 microns spaced ten (10) microns apart reduces the reflectivity of the polymer film and improves robotic vision

There may be a need for various thicknesses of the second polymer layer **412** at different locations on the die **202** for a particular form, fit or sizing requirement. The thickness of the second polymer layer **412** is reducible using the method in accordance with the invention. First, the entire die **202** is covered with the second polymer layer **412**. Then, the second polymer layer **412** is subjected to a photo-imaging process using the photomask **1900** that has partial-depth patterns on a portion corresponding to the portion of the polymer layer on the die **202** that needs thinning. After exposure and developing in accordance with the invention, the thickness of the polymer material on the portion of the second polymer layer **412** that was targeted is less than the thickness of the surrounding polymer material. Alternatively, the entire second polymer layer **412** of the die **202** is thinned in this manner. In either case, the partial-depth producing patterns on the photomask **1900** can be of almost any shape. It is advantageous to thin the polymer layer **214** in accordance with the invention rather than initially disposing less polymer, when it is necessary to thin the photo-imageable layer to a thickness that is less than a thickness that a photo-imageable coating process can achieve with a given material.

While the present invention has been described with respect to preferred embodiments thereof, such description is for illustrative purposes only, and is not to be construed as limiting the scope of the invention. Various modifications and changes may be made to the described embodiments by those skilled in the art without departing from the true spirit and scope of the invention as defined by the appended claims.

LIST OF REFERENCE NUMERALS

100	Prior Art Wafer-Level CSP
102	Prior Art Die
106	Prior Art Solder Ball Pads
200	Wafer-Level CSP
202	Die
204	Moats
206	Solder Ball Pad
300	Portion of Wafer
308	Solder Ball
310	Polymer Collar
312	Full-depth Moat
313	Diameter of Central Feature
314	Region within Moat
315	Width of Full-Depth Moat
316	Region without Moat
317	Distance
402	Silicon
404	First Polymer Layer
406	Re-Distribution Layer (RDL)
412	Second Polymer Layer
414	Central Feature
416	Diameter of Solder Ball
502	Residual
701-703	Lines
712	Partial-Depth Moat
715	Width of Partial-Depth Moat
717	Distance
801	Moat Depth
901-904	Rows
912	Partial-Depth Moat
913	Multiplicity of Circles
915	Width of Partial-Depth Moat
917	Distance
1900	Photomask
1903	Quartz
1905	Chrome
2000	Portion of the Photomask
2002	Central Chrome Circle
2004	Chrome Ring
2006	Diameter of Central Chrome Circle
2008	Width of Chrome Ring
2010	Diameter of Chrome Ring

2100	Portion of Photomask
2101-2103	Concentric Chrome Lines
2104	Partial-depth Producing Chrome Pattern
2105	Width of Each Concentric Chrome Line
2106	Width of Partial-depth Producing Pattern
2107	Diameter of Partial-depth Producing Chrome Pattern
2200	Portion of Photomask
2201-2204	Rings of Circles
2205	Partial-depth Producing Chrome Pattern
2206	Small Chrome Circles
2207	Width of Partial-depth Producing Chrome Pattern
2300	Cross-sectional View
2301	Polymer Film
2302	Distance
2303	Mirror
2311-2319	Arrows Representing UV Light
2320	Surface of Second Polymer Layer
2321-2323	Portions Not Exposed to UV Light
2331-2333	Portions Exposed to UV Light
2400	Cross-sectional View
2401	Partial-depth Feature
2410-2411	Upper Portions of Second Polymer Layer
2413	Minimum Structurally Sound Material Width
2415	Lesser Depth of Partial-depth Feature
2416	Greater Depth of Partial-depth Feature
2417	Width of Partial-depth Feature
2418	Smaller Width of Partial-depth Feature
2419-2420	Angled Side Walls of Partial-depth Feature